Space Environment
TOPICS

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SE–10

Radio Wave Propagation

The Sun's electromagnetic radiation is a continuum that spans radio wavelengths through the infrared, visible, ultraviolet, x-ray, and beyond. Ultraviolet radiation, through a process termed photo ionization, interacts with upper atmospheric constituents to form an ionized layer called the ionosphere.

The ionosphere affects radio signals in different ways depending on their frequencies (see Figure 1), which range from extremely low (ELF) to extremely high (EHF). On frequencies below about 30 MHz the ionosphere may act as an efficient reflector, allowing radio communication to distances of many thousands of kilometers. Radio signals on frequencies above 30 MHz usually penetrate the ionosphere and, therefore, are useful for ground-to-space communications.

The ionosphere occasionally becomes disturbed as it reacts to certain types of solar activity. Solar flares are an example; these disturbances can affect radio communication in all latitudes. Frequencies between 2 MHz and 30 MHz are adversely affected by increased absorption, whereas on higher frequencies (e.g., 30–100 MHz) unexpected radio reflections can result in radio interference.

Scattering of radio power by ionospheric irregularities produces fluctuating signals (scintillation), and propagation may take unexpected paths. TV and FM (on VHF) radio stations are affected little by solar activity, whereas HF ground-to-air, ship-to-shore, Voice of America, Radio Free Europe, and amateur radio are affected frequently. Figure 2 illustrates various ionospheric radio wave propagation effects. Some satellite systems, which employ linear

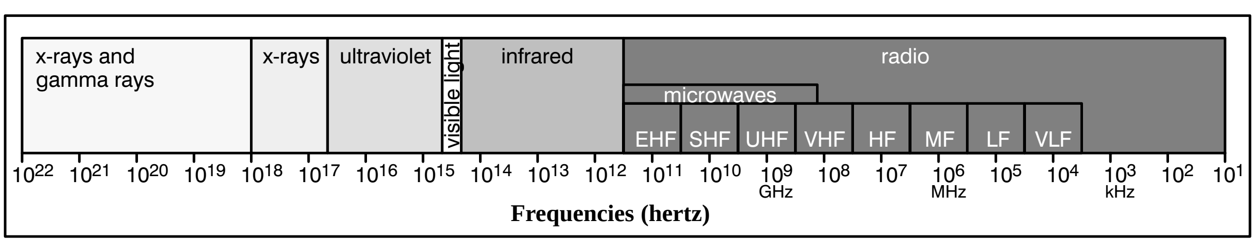

Figure 1. *The electromagnetic spectrum includes x-rays, visible light, and radio waves.*

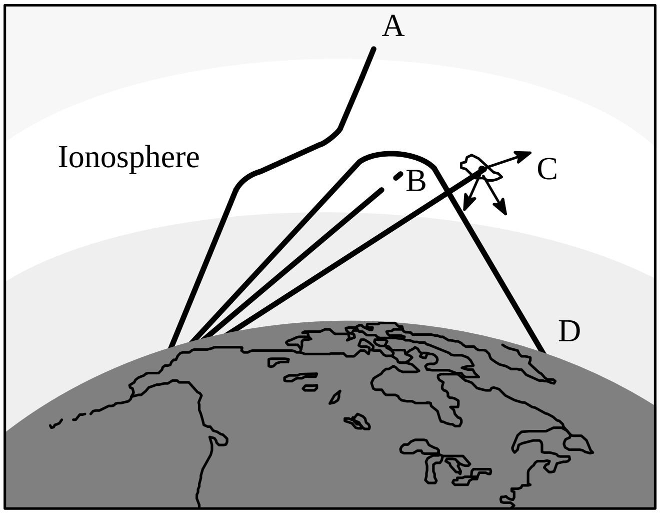

Figure 2. *Radio waves that reach the ionosphere can go astray.*

- *A. Wave penetrates the ionospheric layer.*
- *B. Wave is absorbed by the layer.*
- *C. Wave is scattered in random directions by irregularities in the layer.*
- *D. Wave is reflected normally by the layer.*

polarization on frequencies up to 1 GHz, are affected by Faraday rotation of the plane of polarization.

Solar Flare Effects

A solar flare is a sudden energy release in the solar atmosphere from which electromagnetic radiation and, sometimes, energetic particles and bulk plasma are emitted (Figure 3). A sudden increase of x-ray emissions resulting from a flare causes a large increase in ionization in the lower regions of the ionosphere on the sunlit side of Earth. A sudden ionospheric disturbance (SID) of radio signals can ensue. An SID can affect very low frequencies (e.g., OMEGA) as a sudden phase anomaly (SPA) or a sudden enhancement of signal (SES). At HF, and sometimes at VHF, an SID may appear as a short-wave fade (SWF). This disturbance may last from minutes to hours, depending upon the magnitude and duration of the flare.

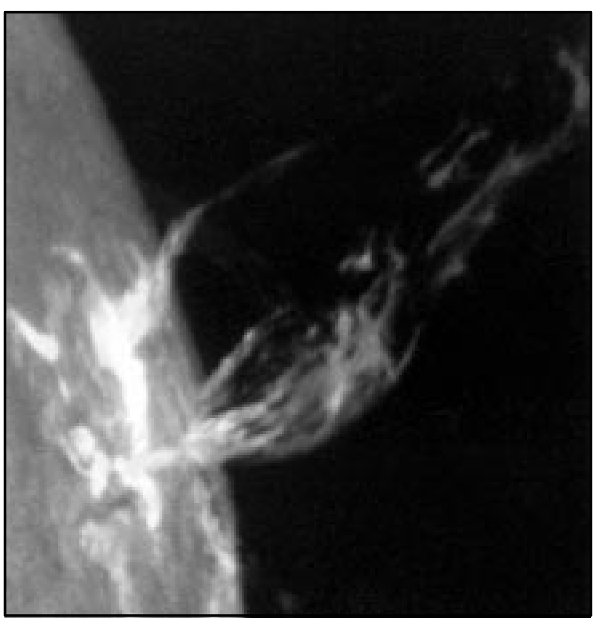

Figure 3. A eruption on the limb of the Sun. This picture was taken in Hydrogen-α light (656.3 nm).

Solar flares also create a wide spectrum of radio noise; at VHF (and under unusual conditions at HF) this noise may interfere directly with a wanted signal. The frequency with which a radio operator experiences solar flare effects will vary with the approximately 11-year sunspot cycle; more effects occur during solar maximum (when flare occurrence is high) than during solar minimum (when flare occurrence is very low). A radio operator can experience great difficulty in transmitting or receiving signals during solar flares.

Energetic Particle Effects

On rare occasions a solar flare will be accompanied by a stream of energetic particles (mostly protons and electrons). The more energetic protons, traveling at speeds approaching that of light, can reach Earth in as little as 30 minutes. These protons reach the upper atmosphere near the magnetic poles (Figure 4). The lower regions of the polar ionosphere then become heavily ionized, and severe HF and VHF signal absorption may occur. This is called a polar cap absorption (PCA) event. PCA events may last from days to weeks, depending upon the size of the flare and how well the flare site is magnetically connected to Earth. Polar HF radio propagation often becomes impossible during these events.

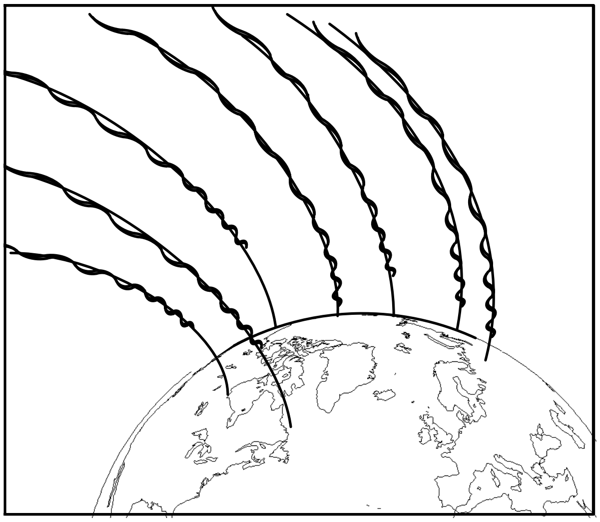

Figure 4. Solar energetic particles following Earth's magnetic field lines can penetrate the upper atmosphere near the magnetic poles, resulting in ionization and creating a polar cap absorption event.

Geomagnetic Storm Effects

Sufficiently large or long-lived solar flares and disappearing filaments (DSF) are sometimes accompanied by the ejection of large clouds of plasma (ionized gases) into interplanetary space. These plasma clouds are called coronal mass ejections (CME). A CME travels through the solar wind in interplanetary space and sometimes reaches Earth (Figure 5).This results in a world-wide disturbance of Earth's magnetic field, called a geomagnetic storm. Another type of solar activity, known as a coronal hole (CH), produces high-speed solar wind streams that buffet Earth's magnetic field (Figure 6); geomagnetic storms that may be accompanied by ionospheric disturbances can result.

These ionospheric disturbances can have adverse effects on radio signals over the entire frequency spectrum, especially in auroral latitudes. In particular, HF radio operators attempting to communicate through the auroral zones (the regions of visible aurora, or "Northern Lights") during storms can experience rapid and deep signal fading due to the ionospheric

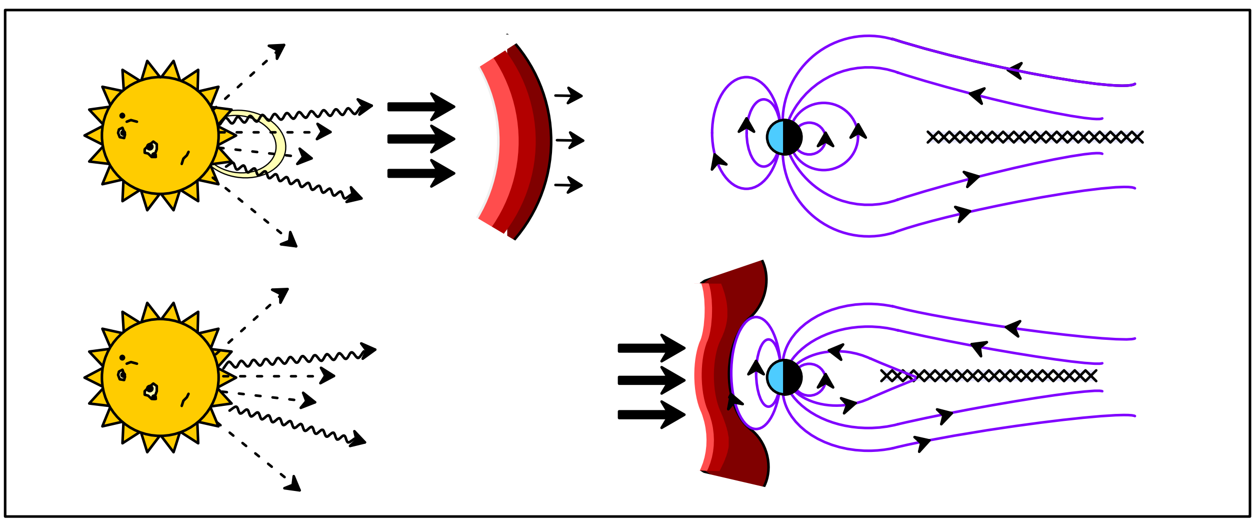

Figure 5. An ejection from the Sun travels to Earth and distorts Earth's magnetic field, resulting in geomagnetic activity.

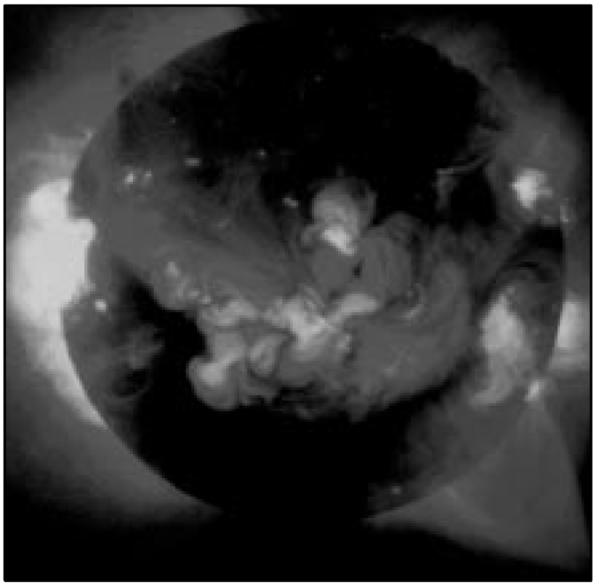

Figure 6. The Sun as seen in x-rays. The darkest areas are coronal holes; bright areas overlie active regions.

irregularities that scatter the radio signal. Auroral absorption, multipathing, and non-great-circle propagation effects combine to disrupt radio communication during ionospheric storm conditions. During large storms the auroral irregularity zone moves equatorward. These irregularities can produce scintillations that adversely impact phase-sensitive systems on frequencies above 1 GHz (e.g., the Global Positioning System). Geomagnetic storms may last several days, and ionospheric effects may last a day or two longer.

Systems affected by solar or geomagnetic activity:

HF Communications

- Increased absorption
- Depressed Maximum Usable Frequencies (MUF)
- Increased Lowest Usable Frequencies (LUF)
- Increased fading and flutter

Surveillance Systems

- Radar energy scatter (auroral interference)
- Range errors
- Elevation angle errors
- Azimuth angle errors

Satellite Systems

- Faraday rotation
- Scintillation
- Loss of phase lock
- Radio Frequency Interferences (RFI)

Navigation Systems

- Position errors

References

K. Davies, *Ionospheric Radio*, P. Peregrinus, London, 1990.

J.K. Hargreaves, *The Upper Atmosphere and Solar-Terrestrial Relations*, Van Nostrand Reinhold Co., New York, 1979.

M.C. Kelley, *The Earth's Ionosphere*, Academic Press, 1989.

P.A. Simon, G. Heckman, and M.A. Shea, *Solar-Terrestrial Predictions*, NOAA/ERL, Boulder, 1986.

The Space Environment Laboratory monitors and forecasts these phenomena:

Solar events that may affect radio propagation.

Geomagnetic activity that may affect ionospheric conditions.

Solar proton events that may affect ionospheric conditions in the polar cap.

Full descriptions of these and other products and services are available from the Space Environment Laboratory:

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